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GREENHOUSE CONSTRUCTION AND HEATING

GLASS FARMING, or the growing of flowers and vegetables in greenhouses, has become an important industry in the United States, and according to the 1919 census the value of the crop for that year was more than $77,000,000, produced in structures covering nearly 3,800 acres.

High-quality greenhouse products are finding an increasing demand, and the industry offers special inducements to those having a knowledge of and a liking for the work.

Vegetables produced in forcing houses near the markets reach the consumer in a fresh condition, without the delays incident to long shipment.

Products of exceptionally high quality can be grown under glass, as conditions are more nearly under control than in the open.

In selecting a location for a greenhouse industry particular attention must be paid to the labor and fuel supply; also to the accessibility to markets.

This bulletin discusses the construction and heating of greenhouses, giving such information as will be useful to those who contemplate engaging in the business.

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GREENHOUSE CONSTRUCTION AND HEATING.

By JAMES H. BEATTIE, *Horticulturist, Office of Horticultural and Pomological Investigations, Bureau of Plant Industry.*

CONTENTS.

IMPORTANCE OF THE GREENHOUSE INDUSTRY.

THE PRODUCTION of greenhouse crops in the United States is an important industry and is constantly increasing because of the demand for vegetable and floral products that can be produced in the modern greenhouse. Furthermore, under favorable conditions the cost of growing greenhouse crops permits the products being sold on the northern markets in competition with those shipped long distances from warmer portions of the country. The fact that greenhouse products are acknowledged to be superior in quality to those grown out of doors contributes materially to the development of the industry. According to the 1919 census there were in the United States more than 17,000 establishments employing some type of forcing structure for the production of plants, flowers, or vegetables. The value of the crop grown in 1919 was about $77,000,000, the glass area covering nearly 3,800 acres.

Success in growing vegetables or flowers under glass, in addition to the skill of the grower, will depend upon the suitability and adequacy of his equipment and the use which is made of it. The fact that the quantity of coal used to maintain each acre of space inclosed in greenhouses at the required temperatures varies from 250 to 500 tons a season indicates the need for the practice of every possible economy. Any feature of the construction of the greenhouse plant, its operation, or its upkeep which affects the quantity of fuel consumed immediately reflects itself as an item of cost in the production of greenhouse crops. Fuel losses in greenhouse heating are sustained because of poorly constructed houses, a faulty heating system, or the lack of repair of the house or the heating unit. As the principles of construction and heating come to be better understood it is altogether

likely that greenhouse crops will be more economically produced, thus putting the operator on even a more favorable basis than at present as compared with producers of outdoor crops that are shipped long distances and take a high freight rate.

The production of such vegetables as lettuce, cauliflower, beets, and radishes can be carried on in simple, inexpensive houses. The starting of the plants of cabbage, tomato, eggplant, pepper, and celery can be carried on with even simpler equipment. It is likewise possible to grow many floral or decorative crops in greenhouses requiring only a moderate outlay for their construction and equipment. In many cases the same houses may be used for both flowers and vegetables, but this practice is not usually followed except in small establishments.

Forcing houses are usually a profitable investment when operated in connection with a market-gardening or truck-crop enterprise. Many persons have found a greenhouse to be an excellent means for the utilization of a portion of their time. There are few enterprises so well suited to the needs of middle-aged or older persons who want some form of work as an entire or partial source of livelihood. Not all locations are adapted to greenhouse work, and the advisability of the undertaking for the individual must be determined after a careful study of the conditions. Most of the large greenhouse enterprises had their beginning in a small way, and it is always well for the beginner to locate his enterprise so that he will have room for expansion. Where there is but little chance that the enterprise will develop into a large business there may be an excellent opportunity for profitable plant growing to supply persons in the immediate vicinity.

LOCATIONS SUITED TO GREENHOUSES.

In locating commercial greenhouse ranges several factors should be considered, the most important of which are (1) fuel supply, (2) labor, (3) marketing facilities, (4) soil, and (5) water. It requires from 250 to 500 tons of coal to maintain an acre of glass at the proper temperature for the season. The lower figure refers to ranges growing cool crops, such as lettuce, where the temperature is maintained at 40° to 55° F.; the higher figure, to ranges growing crops demanding temperatures up to 75° F. Greenhouse plants so located that they can obtain cheap fuel have a distinct advantage over those less fortunately situated. A large plant should be so located either on a railroad or a canal that fuel can be placed in the boiler room without expensive handling. Contrary to the general belief, there is no marked variation in the quantity of fuel required for greenhouse establishments located in the different sections of the country. Many have been located at a distance from large markets because the fuel required could be secured more cheaply. Marked economies may result from such a location, as the weight of the fuel required to produce a greenhouse crop is many times the weight of the crop itself, and it may be cheaper to ship the crop than to ship the fuel.

An abundance of specially trained labor is essential to success in the greenhouse industry. Highly intensive working of the soil, such as is necessary to success in this business, requires that every square

foot in the houses be utilized to the fullest extent, and this requires considerable labor. The average annual value of the greenhouse crop of the United States is about $20,000 per acre, and it is evident that each acre of glass will readily furnish profitable employment for two or three men. While it may be easier to obtain labor in sections where the industry is already developed, this need not be a deciding factor in the location of a greenhouse, as help can soon be trained to perform the work in a satisfactory manner.

Nearness to market is desirable in many ways, but this need not be a deciding factor. It may be a better plan to build the greenhouse range where cheap land, fuel at low cost, and plenty of labor can be had, provided good shipping facilities are available. It is essential that the crop be placed on the market in the shortest practicable time, and the location of the plant where the product can be moved by truck, by fast express, or by other means that will put it on the market a few hours after it is harvested undoubtedly has a distinct advantage. Although it is desirable that the greenhouse enterprise be located on good soil, this is not an essential, as good soil can soon be developed. When it is possible to make a selection of the type of soil on which the plant is to be located, a loam is to be preferred for most purposes. In houses without benches the natural soil is usually employed, while in houses fitted with benches and in other houses where the soil is changed from time to time it is possible to modify it to suit the crops to be grown.

Greenhouse crops require large quantities of water, and an ample never-failing supply should be assured. For small enterprises it is usually more economical to use water from the city mains if it can be obtained. Larger plants requiring great quantities of water may find it more economical to maintain their own pumping plant and storage facilities.

The small greenhouse enterprise is often started as an adjunct to some other business, such as a store, and for this reason it is desirable to locate the structure so that the work can be performed easily. Many locations are totally unsuited to even small greenhouses. With the exception of a few crops grown in the dark, sunshine is essential to the growth of greenhouse crops. If the only available location is such that the greenhouse will be shaded for a considerable portion of the time, or if the location is such that excessive amounts of smoke, dust, acid fumes, etc., are present in the air, it may be inadvisable to enter the business. When it is possible to choose a location, a well-drained piece of land should be selected, preferably with a southern slope and where the house will be protected from winds by forests, hills, or artificial windbreaks. In many cases these small greenhouses are cared for by some member of the family, and it is often desirable to heat such a structure with the hot water or steam heater serving the residence. When this plan is to be followed, the greenhouse should be located at a higher level than the heater, to assure circulation.

LAYOUT OF THE PLANT.

The economical operation of a greenhouse plant depends largely upon the plan and arrangement of the units, such as the boiler room, the packing house, and the forcing houses. It is desirable that the

packing room should be accessible to all of the houses without going outdoors or using indirect routes. The arrangement of the houses and of the remainder of the plant will be determined by the type of house to be erected and by the character of the site. Figure 1 illustrates an arrangement often employed for detached houses. It will be noted that this arrangement offers an excellent opportunity for the economical handling of the product. Figure 2 shows a range of ridge-and-furrow houses with the boiler room and workroom so arranged that it is possible to receive coal and manure and handle, pack, and ship the product with the minimum of labor.

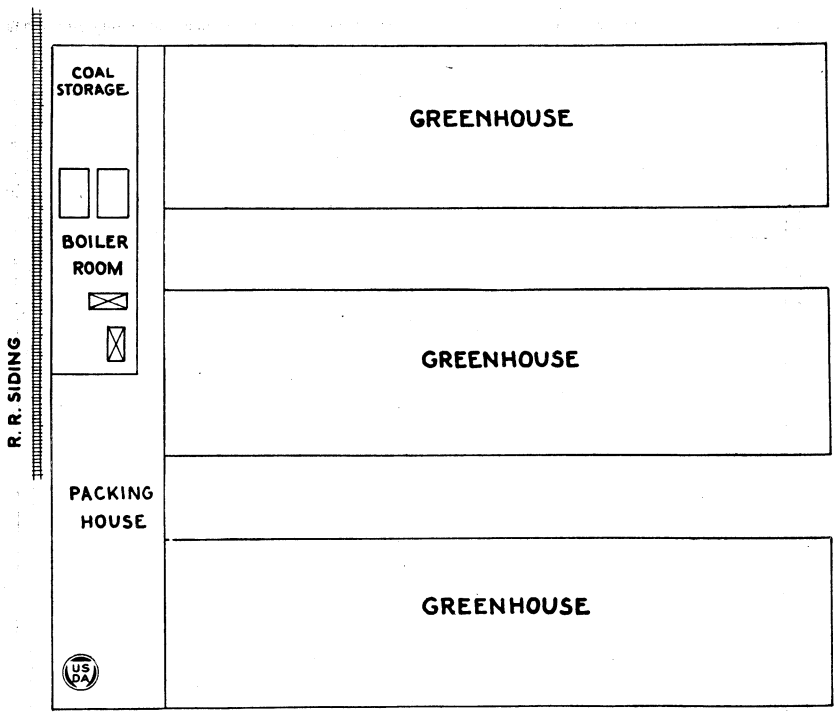

FIG. 1.—Detached greenhouses with head house across one end, a plan often employed in building ranges of such houses. This arrangement facilitates the economical handling of the work.

Figure 3 shows a greenhouse built without thought as to economical operation. The boiler room is far removed from the packing house and is at a higher level than most of the greenhouses. The plant is upside down so far as the heating plant is concerned, as it is necessary to pump all the condensation back to the boilers. No railroad siding is provided, and it is necessary to haul all the fuel to the boiler room and haul all the product to the railway station. Such a plant costs far more to operate than does a well-planned one.

When it is desired to build a commercial range of greenhouses the plan for the whole range should be made at the start, so that the first house will be a unit that will fit in with the later houses, in order to create a harmoniously operating plant. It should be

remembered that most greenhouse ranges have small beginnings and that the location of the first house should have careful consideration.

TYPES OF GREENHOUSES.

Several well-defined types of greenhouses are in use. The simplest is the lean-to house, this having a shed roof, built against some existing structure.

The detached house, as its name signifies, is an independent structure and may be of any size up to one covering from 1 to 2 acres

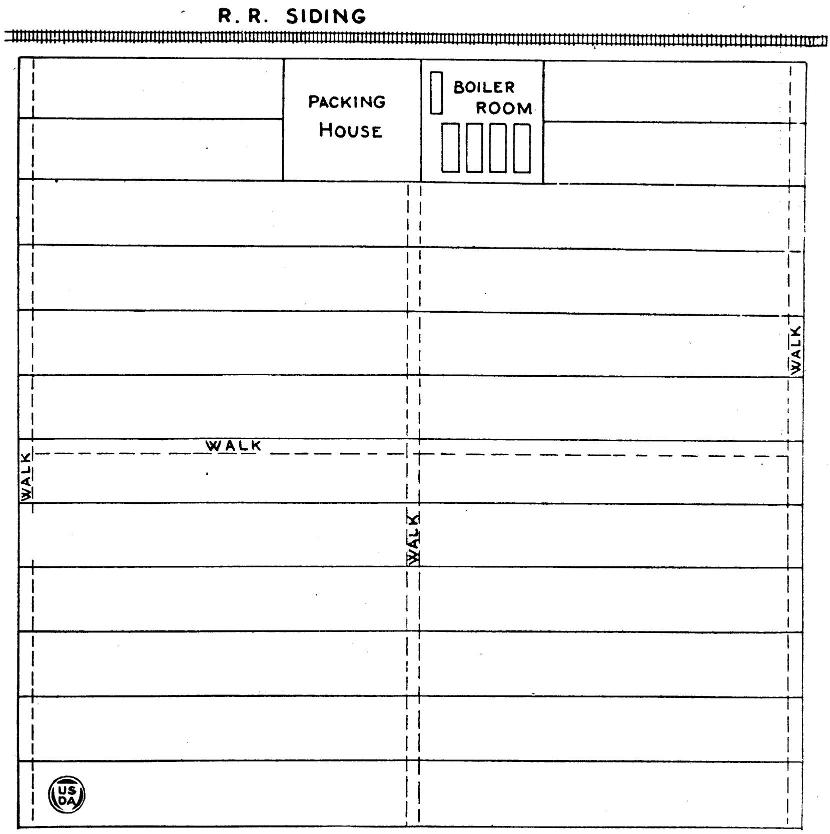

FIG. 2.—A range of ridge-and-furrow houses; an excellent arrangement for reducing labor to a minimum.

of ground. For convenience in operating the plant, such houses are usually built in rows and connected by a head house built across the ends of the houses, as shown in Figure 1.

Another type, known as the "contiguous" house, consists of several independent units built side by side and using the same inside walls.

Another extensively used type is known as the "ridge-and-furrow house," the arrangement of the units in this type being similar to those in the contiguous house, but the inside walls are omitted,

the gutters being carried on posts, giving in reality one large house. (Figs. 4 and 5.)

The lean-to house is simple, inexpensive, and fairly satisfactory for some purposes and some locations. The contiguous type has little to recommend it, except where not more than two are built side by side, thus permitting of side ventilation on one side of each house, a thing that is impossible except in the two outside houses

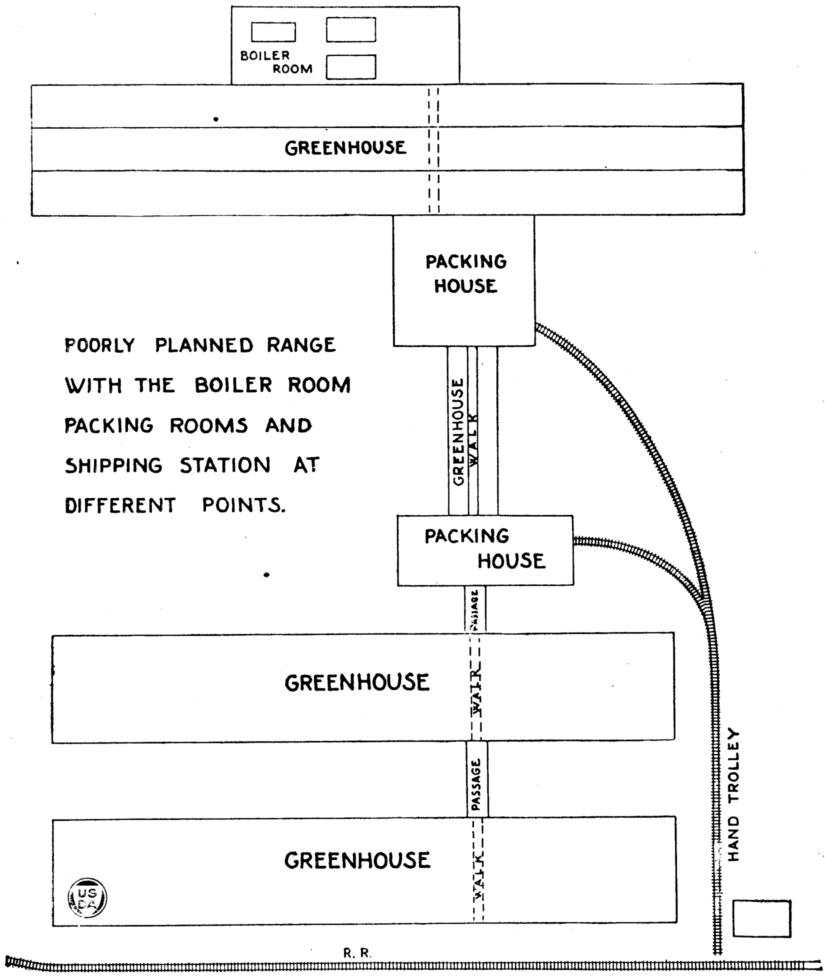

FIG. 3.—A poorly arranged greenhouse plant.

when several are built side by side. Both the ridge-and-furrow and the detached types of houses have much to recommend them, and most of the houses of new construction are of these types. As pointed out in an earlier paragraph, the lean-to house always has a roof sloping one way.

The other types may have roofs with the ridge in the middle of the structure, this being termed an "even-span house," or with the ridge

three-fourths or any other fractional distance from one wall or the other, making an uneven-span roof. Greenhouses with uneven-span roofs are particularly desirable for sidehill locations. Any of these four types of greenhouses may have curved eaves or other special features, but the small house for the beginner should be as simple and as inexpensive as is consistent with the purpose for which it is to be used. When, for instance, it is the purpose to produce vegetable plants, and in some cases some of the more common ornamental bedding plants, such as geraniums and scarlet sage, the houses may be of the simplest construction. If, however, it is the purpose to grow winter vegetables and flowers for sale, the houses must be more elaborate and, of course, more expensive.

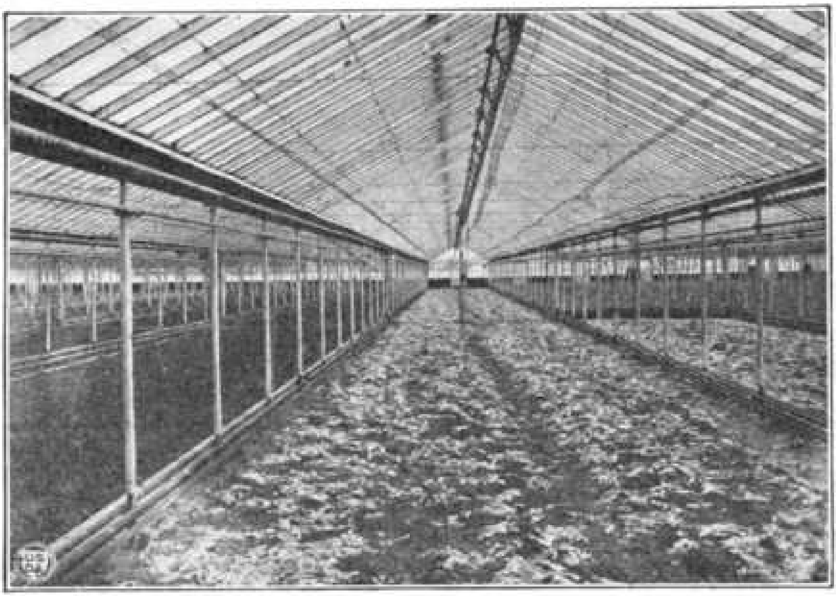

Fig. 4.—Interior of ridge-and-furrow greenhouses.

The necessity for a careful study of the conditions, so as to determine the particular line of work that is most likely to succeed, can not be overestimated. Neither can the advisability of starting with simple equipment and the production of easily grown crops be too strongly urged. Many beginners in the greenhouse business fail because they attempt the production of such difficult crops as violets, roses, orchids, or muskmelons, when they probably would have succeeded with bedding plants, vegetable plants, or even greenhouse lettuce or carnations.

SIZES AND PROPORTIONS OF GREENHOUSES.

It is usually better for those without greenhouse experience to start with a small unit, to which additions can be made. At the same time the house should be so large that it will justify the full time and attention of the operator. A surprisingly large number of plants

can be produced in a well-planned greenhouse of small size. In planning the house, it should be remembered that the proportions of the structure markedly affect the ease with which the work can be handled and the economical use of the space inclosed.

Most of the small houses used by beginners in the business are devoted to crops that make greenhouse benches desirable, and the house should be of such width that the space can be economically divided between walks and benches. They should be so proportioned that there is just room in the walks for the operator, and in the case of a house over 50 feet long for a small truck or wheelbarrow for the placing and removal of the soil, manure, and the plants themselves. When the house is of such length that the use of the truck or wheelbarrow is unnecessary a walk 2 feet wide will be ample. The benches should be of such width that an adult can just reach across them. A lean-to house 6 feet 8 inches wide outside dimensions and with one walk 2 feet wide allows just room enough for one bed 4 feet wide, this being about as wide as the average person can

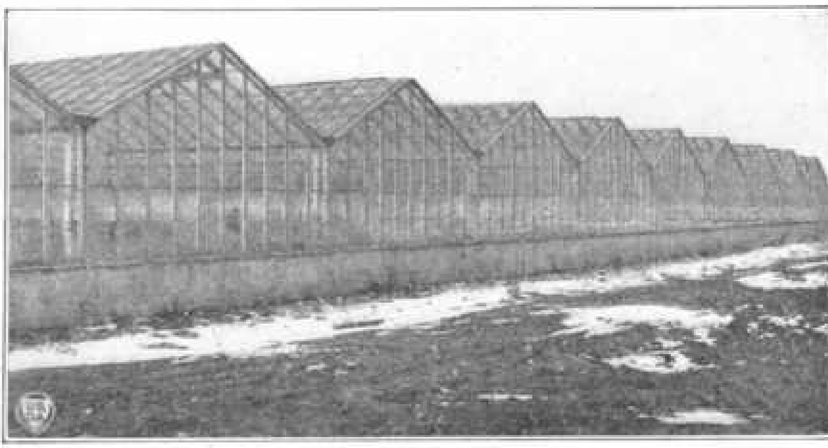

FIG. 5.—Exterior of a range of ridge-and-furrow greenhouses.

reach across. (See Fig. 16.) The house shown in this figure is a type very frequently built by beginners.

Lean-to houses can be built of any desired width and with two or more walks, but this type of house is not at all common. (Fig. 6.) A house 10 feet wide allows room for a 2-foot walk in the middle and two 3½-foot benches.

The same considerations hold for detached houses as are brought out in Figure 17, this showing an even-span house 10 feet wide. Where benches are to be used the next economical width of a house is 20 feet, allowing for two walks, two side benches, and one middle bench about 7 feet wide, the middle of which could be reached from either aisle. (See Fig. 18.) The above considerations as to width do not apply to houses not fitted with benches where the crops are to be grown on the ground or in slightly raised ground beds, as is usually the case with vegetable houses. These structures can be any desired width, as in such houses it is usually possible to cultivate the crops with hoes or other long-handled tools, or from boards rest-

ing on the curbs or on low trestles set on the walks along the sides of the beds. At the present time the tendency is toward very large houses, those 60 to 80 feet wide and 500 to 600 feet long being not uncommon. The house may be of any required size, depending upon the use to be made of it and the character of the site.

GREENHOUSE MATERIALS AND PARTS.

It is always desirable to secure greenhouse materials from concerns making a specialty of their manufacture, as practically all parts of a greenhouse are of special character and have been evolved through many years of experience in building such structures. The earlier houses were of extremely heavy construction, and while strong they were open to the objection that a large portion of the light was kept out by the size of the framework. The structure has

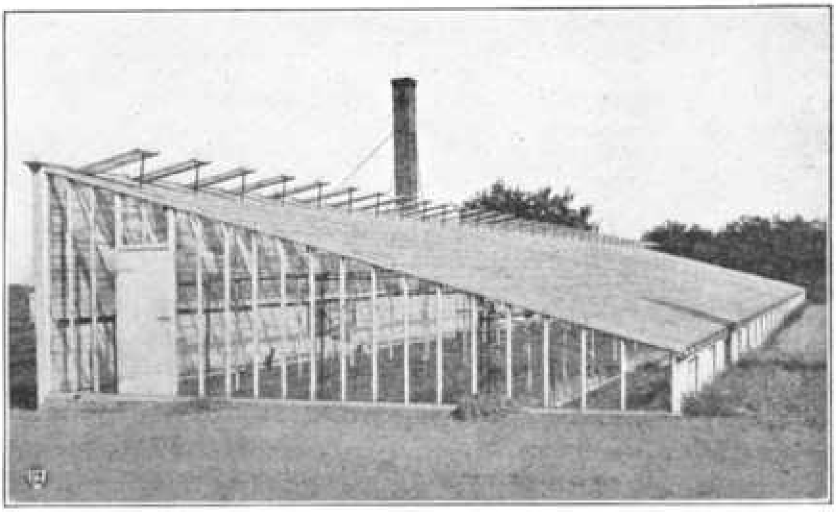

FIG. 6.—Lean-to house with two or more walks, which may be of any desired width. Instead of building the house shown here against some existing wall, it was constructed with one wooden wall.

been gradually lightened through the use of better materials, until the frame of the modern house presents very little obstruction to the entrance of light.

FOUNDATIONS.

The foundation of the greenhouse must not only carry the weight of the structure but must tie it to the ground and support it against the force of the wind and the weight of snow and ice. Many of the difficulties experienced by greenhouse owners have been due to the fact that their houses were built without sufficient foundations. The character of the foundation necessary is determined by the kind of house to be built and by the subsoil. With simple houses supported on wooden posts it may be sufficient to have concrete or masonry footings under these posts, while with semi-iron or steel-frame houses it may be necessary to have continuous footings under

the walls, these to extend below the frost line and to be of sufficient size to support the structure during the heaviest snowstorms and the highest winds. Without sufficient foundation for the house, settling is almost sure to occur, causing the glass to loosen or be broken, the doors to sag, the gutters to get out of line, and a general weakening of the structure.

THE SUPERSTRUCTURE.

The frame of the greenhouse may be of wood or a combination of wood and steel. The all-wood structure, as the name suggests, has wooden posts, sheathing, gutters, sash bars, etc. The portion of the wall from the top of the foundation to where the ventilators begin is usually sheathed, covered with paper, and then sided. The house is fitted with wooden plates and gutters, the latter resting on top of the side posts and with the braces, ties, and purlins frequently used on the inside of the structure made of steel pipe when the width of the house requires such support. Many ridge-and-furrow houses are of this type of construction.

The semi-iron house is a combination of wood and steel members, having as a rule pipe posts embedded in the concrete side walls and an angle-iron eave plate or an iron gutter attached to the posts and sash bars by special fittings. These houses have inside pipe posts with pipe or angle-iron purlins and purlin braces. Such a house is described later. (See Fig. 18.) In this house the pipe posts are embedded in the concrete side walls, the method used being to set the posts in position first and pour the concrete around them. This house is 20 feet wide and has two rows of inside posts, but for narrower houses one row of posts is sufficient. For houses of moderate width this type of construction is admirable.

The steel-frame house differs from the semi-iron house in that the roof is supported by built-up structural members carried by side posts set in the side walls. For houses of this type up to 40 feet wide no inside posts are ordinarily used, while houses as wide as 80 feet can be built with but two rows of inside posts, these being made of steel pipe, steel columns, or of wood. The steel-frame house is generally used for large-sized units. However, the person just starting in the greenhouse business with the idea of growing the simpler crops will usually find a less expensive type satisfactory for his purposes.

Whether the all-wood, the semi-iron, or the steel-frame type of house be selected, the superstructure while sufficiently strong to withstand the hardest storm must be made of parts so small that little shade will be cast. This requirement has led to the general use of iron and steel instead of wood. For certain parts of the greenhouse wood is looked upon as an ideal material, while for other parts iron or steel is best. The uses to which each material is best adapted will be discussed in the following pages.

POSTS.

The posts supporting the greenhouse side walls and roof may be of wood, wrought-iron or steel pipe, or of structural steel in the form of bars, channels, or I beams. The conditions in a greenhouse are particularly favorable for decay or corrosion, and whatever material

is used must be well protected from decay or rusting. Wood should be of a decay-resisting timber, such as redwood, cedar, or locust, and it is usually advisable to soak the portion that goes in the ground in creosote or some other wood preservative, and embed it in concrete. Figure 7, *C*, shows the usual method of constructing greenhouse walls with wooden posts. When iron-pipe posts are used for the outside walls they are as a rule set in concrete. (See Fig. 7.) Wooden posts are employed only when wooden gutters are used and the gutter is secured to the top of the posts. When steel posts or pipe posts are used, either with wood or semi-iron houses, the gutter or angle-iron eave is secured to the posts by means of special post top fittings. (See Fig. 8, *A*.) When the steel-frame house is employed, the roof trusses are riveted to the posts, using special post top fittings.

Inside posts may be of wrought-iron, steel pipe or structural steel, or of wood. The tendency is toward the use of steel pipe or structural steel, as this class of material is light, strong, and of small size as compared to wooden members suitable for the same uses. (Fig. 8, *B*.) In wider houses the same material is used, as is brought out in Figure 8, *C*. In all cases where pipe is used for inside posts and braces it is necessary to use special fittings to fasten the members together, as shown in Figure 8.

BRACES, TIES, AND PURLINS.

The sash bars carrying the glass must be supported at close intervals by the frame of the greenhouse. The distance between these supports varies with the type of house and the size of the sash bar, but unless these supports are spaced not over 8 feet apart trouble is likely to be experienced through sagging and possible breakage, especially under heavy loads of ice and snow. The purlins employed to give this support in wooden or semi-iron houses are of angle iron, I-beam steel, or pipe. They are either carried on top of posts or by braces to the posts. (See Fig. 8, *B* and *C*.) In steel-frame houses the purlins are carried either on posts or by the trusses supporting the roof.

The greenhouse must bear heavy strains due to winds, snow, and ice and must be well braced so that it will be perfectly rigid. The side walls of wood and semi-iron houses are usually tied together at the eaves with rods fitted with turnbuckles. There is a tendency for the houses to spread, owing to the weight of the roof, and these ties counteract this. The tie rods are usually spaced about 10 feet apart. The roof is also braced against twisting by tie rods running in diagonal directions from the purlin braces to the eaves. These braces are usually installed only every third or fourth set of purlin braces. Even in steel-frame houses this bracing is desirable.

GUTTERS AND EAVE PLATES.

The wooden gutter is expensive and unless kept well painted is short-lived and liable to leak through the joints. Cast-iron and steel gutters are used and give satisfactory results, but must be kept well painted, or they, too, will deteriorate. In houses such as ridge-and-furrow houses and contiguous houses inside gutters must be used,

and these should be of as simple construction as possible. Figure 7, *B*, shows a type of gutter that is simple and efficient.

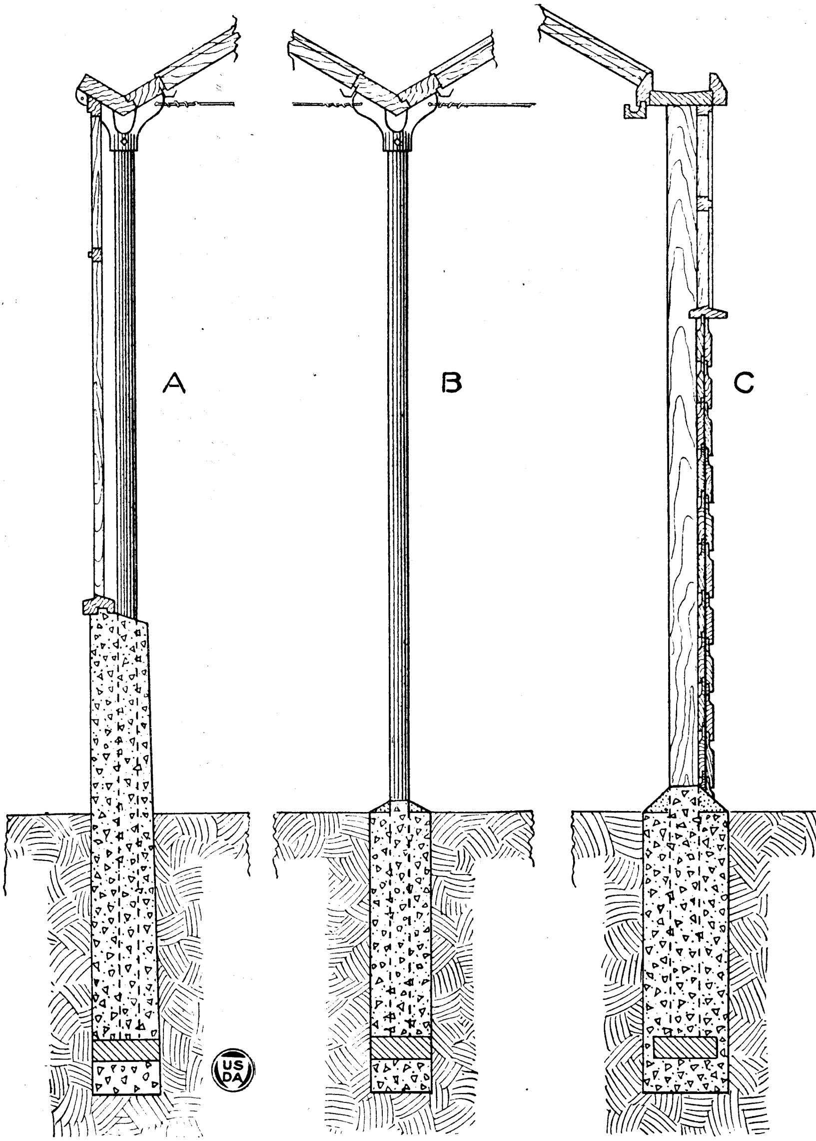

FIG. 7.—Detailed plans of walls, posts, and gutters for a ridge-and-furrow house: *A*, Outside wall with iron post embedded in concrete; post top fitting and wooden gutter construction. *B*, Inside gutter with iron-pipe post. *C*, Outside wall, wooden post, gutter, and sheathing.

Many detached houses are now being built fitted with angle-iron eave plates, such as are illustrated in Figure 8, *A*. The house shown on the title-page of this bulletin is built in this manner. Such construction is long lived, strong, and does not allow snow and ice to

lodge on the eaves of the house, but, of course, does not collect the water running off the roof and convey it to the sewer. Provision for such drainage can be made by constructing a gutter alongside the greenhouse, into which the water can fall from the roof.

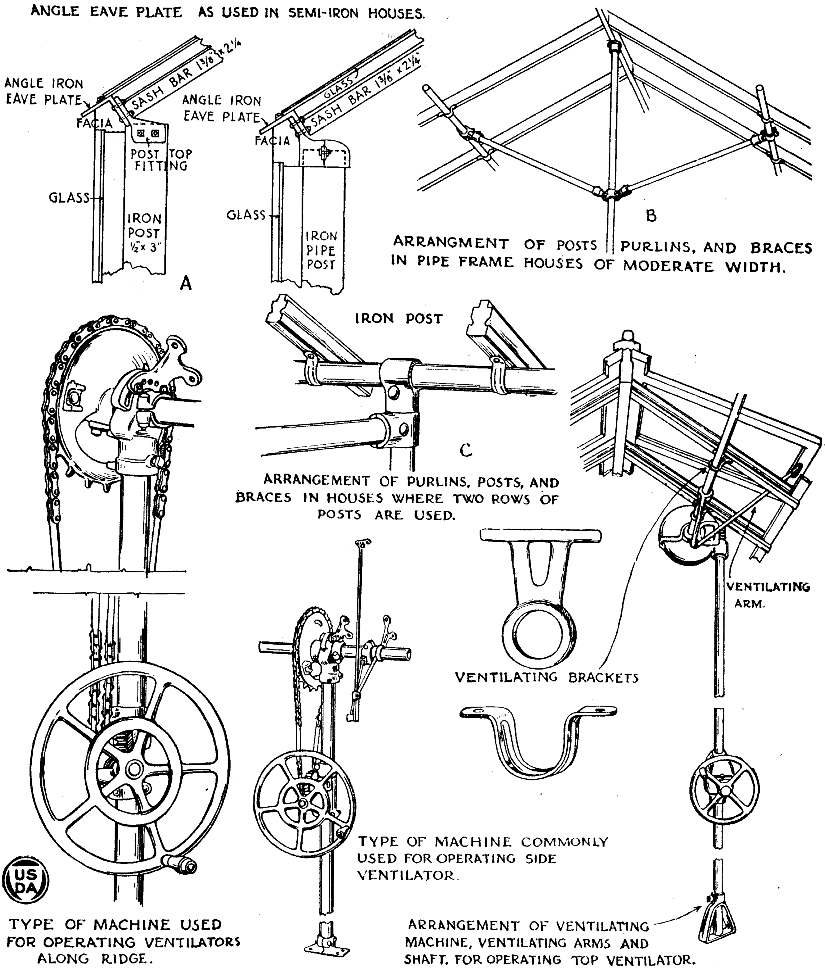

FIG. 8.—Details of construction of special features for a wooden or semi-iron greenhouse: *A*, Iron and iron-pipe posts with special top fittings. *B*, Arrangement of inside posts and braces where one row of inside posts is used. *C*, When two rows of posts are used they are usually placed under the purlins and tied together as shown.

RIDGE CONSTRUCTION.

In wooden and semi-iron greenhouses the ridge members are usually of wood. (Fig. 9.) The size and type of the ridge parts are determined by the character and size of the house, but typical ridge parts are shown in the illustration. It will be noted that the sash bars are inserted so far below the top of the ridgepole that there is room between the top of the sash bars and the cap for the ventilator sash. In some steel-frame houses the wooden ridge parts are carried on

top of a steel I beam, this construction being made necessary on account of the methods used in constructing the roof frame. The wooden parts are used for convenience in attaching sash bars, cap, and ventilators.

SIDE WALLS AND ENDS OF THE GREENHOUSE.

The portion of the side walls of the greenhouse not occupied by masonry foundations and ventilating sash is constructed of sash bars and glass. In cases where high masonry walls are used, the remainder of the side walls is usually taken up with ventilators. (Fig. 10.) In cases where the ventilators occupy but part of the

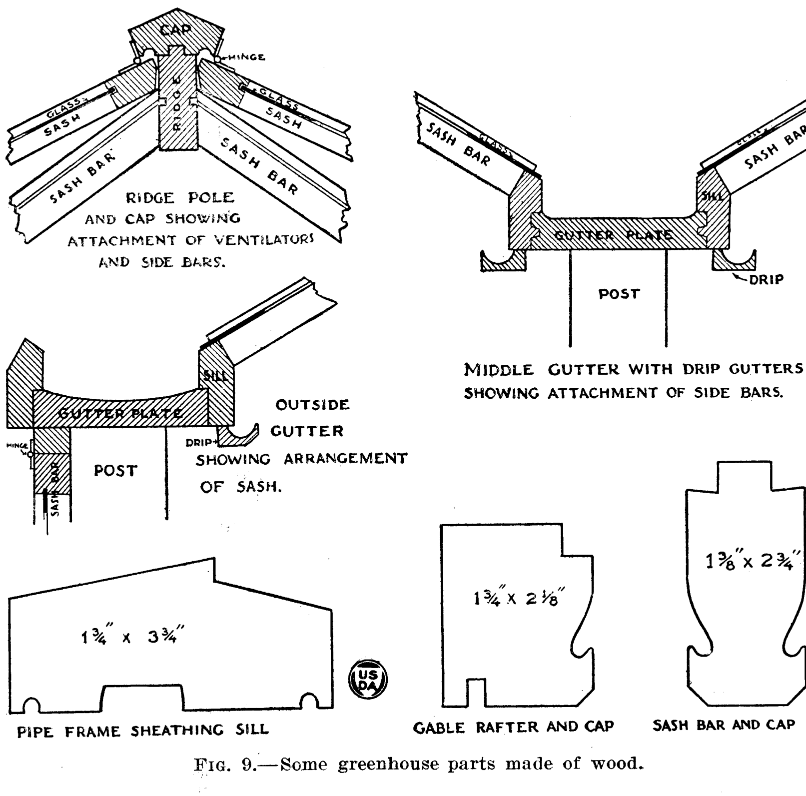

FIG. 9.—Some greenhouse parts made of wood.

space between the top of the masonry walls and the eaves, it is necessary to use a plate located at the bottom of the ventilators, this serving as an attachment for the sash bars.

Aside from the portion occupied by masonry construction and doors, the ends and gables of the greenhouse are usually of sash-bar and glass construction. Owing to the pressure exerted by the wind on such exposed parts, it is necessary that the gable end be well braced. In small houses the area exposed is so small that the purlin ends are a sufficient brace. In semi-iron houses a set of posts and purlin braces is sometimes placed at each end to give strength to the structure. In steel houses one of the roof trusses is placed at each end and the gables attached to these. The doors are nearly always

placed in the ends of the greenhouse. In large structures these doors should be of such size that easy access can be had to the struc-

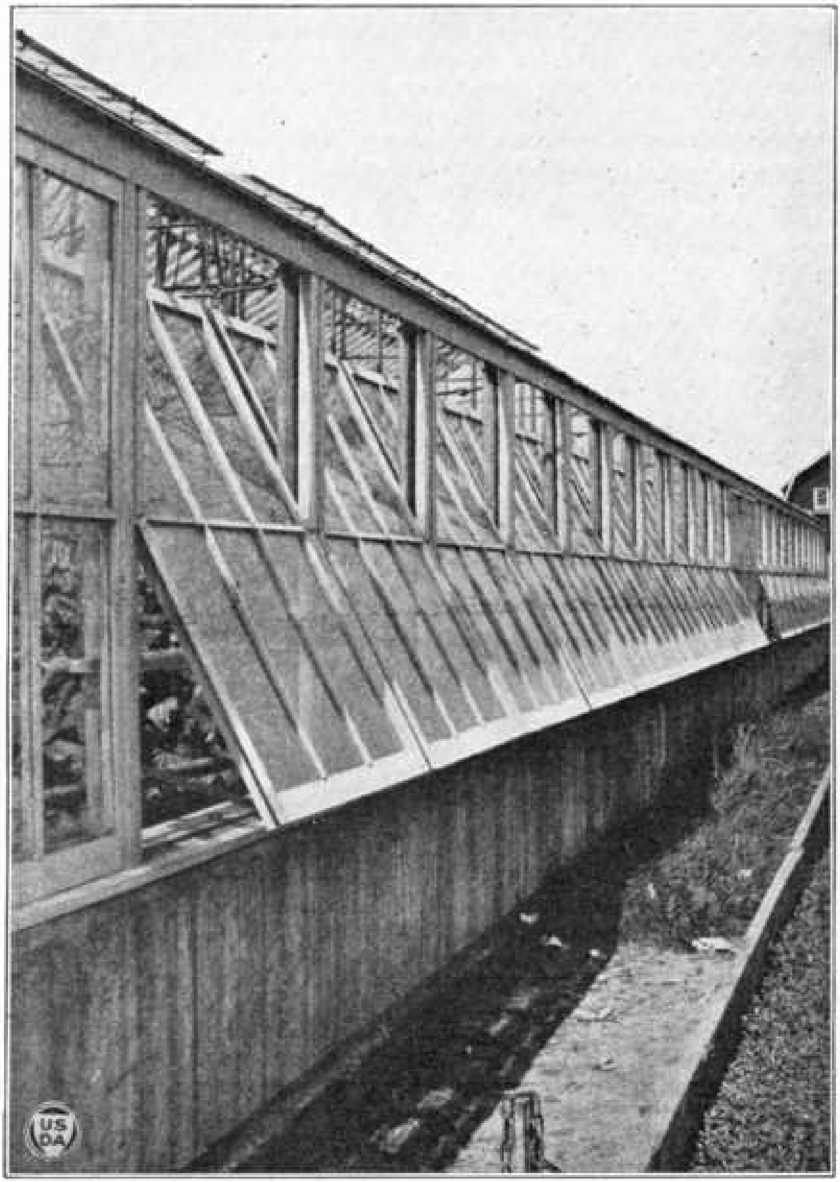

FIG. 10.—A type of construction where the portion of the wall of the greenhouse between the masonry and the gutter is taken up with ventilators.

ture for the placing and removal of soil, manure, and implements required in the work. (Fig. 11.)

SASH BARS.

The sash bars in a greenhouse serve the same function as the rafters in a house—that is, they carry the roof itself, in this case the glass. The usual form of wooden sash bar is illustrated in Figure 9. Sash bars are made in a variety of sizes and shapes. There are several makes of metal sash bars, but wood is most largely used. Heart cypress is the material ordinarily selected for the making of sash bars, and needless to say it should be of first grade. Where it is possible the bars should run the full length of the roof without splices, but in wide houses it is necessary that splices be made, and extreme care should be exercised to make these tight and strong. Owing to the small size of the sash bar, metal plates, as a rule, are used to make the splice strong.

FIG. 11.—Hauling manure into a greenhouse fitted with doors in the ends large enough to admit a team and dump wagon.

Sash bars are spaced to accomodate the width of the glass to be used. Most greenhouse glass is 16 inches wide by 24 inches long. The sash bars have a tongue one-half or five-eighths of an inch wide, and this comes between the different courses of glass, so the sash bars must be spaced 16½ or 16⅝ inches apart, as the case may be. As a rule, no extra clearance for the glass need be left, but where the sash-bar tongues are full dimension and are heavily coated with paint an additional clearance or space of one thirty-second to one-sixteenth of an inch should be allowed, so that the glass will fit close but not bind along its edges. In houses using angle-iron eave-plate construction the sash bars are attached by special fittings, these being bolted or riveted to the plates. The sash bars are attached to pipe purlins by clips, such as are shown in Figure 8, *C*, to angle purlins by bolts or screws, and to the ridgepole by screws or nails.

MISCELLANEOUS STRUCTURAL PARTS.

Practically every part of the greenhouse is of special construction, having been developed through a long period of time and especially adapted to some particular part of the structure. In the foregoing paragraphs some of these special fittings and parts have been described. Figures 8 and 9 show these and other parts. It is never advisable to attempt to use any but the parts and fittings adapted to the purpose. These can be procured from firms making a specialty of their manufacture.

VENTILATION.

Any greenhouse, however small, must be fitted with suitable means for ventilating the structure. In the lean-to house, such as is shown later (see Fig. 16), the ventilators as a rule are placed in the side walls below the gutter and in the roof along the ridge. In detached houses, side ventilation and roof ventilation are usually deemed necessary. The ventilators in any house may be placed at intervals of every few feet or may be a continuous line of sash extending the length of the house. For most types of houses the latter kind is preferable. For roof ventilation the sash is hinged at the ridge, the joint being protected by a cap extending over each side of the ridgepole. (Fig. 9.) The ventilators are operated by a machine so arranged that it is within convenient reach of the operator. Figure 8 shows the arrangement of the ventilators and ventilating machines in a medium-sized house. Ventilating machines capable of operating long lines of sash can be obtained, but it is never wise to overload the machines by attaching them to longer lines of sash than they are designed to handle, or breakage may result. In small houses it is sometimes feasible to avoid the expense of a ventilating machine by simply raising the individual ventilating sash and securing it at the desired height with a notched stick or flat iron bar attached to the ventilator sash, with holes every 2 or 3 inches which allow the bar to be secured at any desired point. Such devices are not very satisfactory and should be employed only as temporary expedients.

Side ventilators may be hinged at the top where the joint can be protected by a drip cap, or they may be pivoted in the middle. The illustration on the title-page shows a house with hinged ventilators and Figure 10 one equipped with the pivoted type.

The latter type has many points of advantage, chief of which is the greater ventilation given, but the workmanship must be of the best or trouble will be experienced due to sticking. On the other hand, if too loose, excessive loss of heat will occur. Side ventilators as a rule are operated by machines, but they can be opened and closed by hand. Figure 8 shows some of the more important parts of the ventilating equipment. Planning the greenhouse so that standard-sized sash can be used for ventilators makes it possible to secure these along with the other greenhouse material.

PAINTING AND GLAZING.

Moisture conditions existing in the greenhouse make it particularly desirable that all parts be kept well painted. At least one coat of paint should be applied before the structure is erected. For wooden parts a white-lead, zinc, and linseed-oil paint is best, while a red-lead

oil paint is satisfactory for the metal parts. After erection, at least two coats of paint should be given, and it is a good practice to apply at least one coat each year thereafter. New sash bars should have at least two coats of paint before the glass is placed. Unless this is done the putty is liable to come loose through having its oil absorbed by the fresh wood.

There is a great difference in the light-transmitting qualities of different grades of glass, and it is especially important that a good grade be used. The best glass is designated "AA," while the next grade is "A" and the third "B." Grade A glass costs much less than the AA grade and is usually satisfactory for greenhouse glazing. The tendency at the present time is to use large glass, as this means fewer sash bars to cast shadows in the houses. Most of the houses now being built are arranged for glass 16 inches wide by 24 inches long. The glass is lapped one-eighth of an inch, this being sufficient to prevent leakage. A greater lap than this would be likely to cause breakage, due to the freezing of moisture between the panes.

Greenhouse glass is bedded in putty or some other glazing compound for the purpose of making the roof water-tight and to exclude cold air. The putty or other glazing material may be applied to the sash bars, the glass pressed down into it and then secured in place with special five-eighths-inch glazing nails, two about 2 inches from the end of the pane, two about the middle, and two directly below the lower edge of the pane, to keep it from slipping downward. In setting the glass it should be remembered that most glass is slightly curved, or is "right" and "left" according to the term used by glaziers. The glass should all be placed with the curve up, so that the joints will be perfectly tight.

GREENHOUSE HEATING.

Fuel is one of the large items of expense in the operation of a greenhouse. Economical heating equipment properly handled is essential to the profitable operation of the plant, and careful attention to the planning and installation of this part of the equipment of the greenhouse is necessary. The finest greenhouse may give unsatisfactory results because of poor heating facilities. There are many forms of heating equipment for greenhouses, and the one best adapted to the needs of a particular case must be determined by such considerations as the size and type of the house, the crops to be grown, the attention that can be given the heating plant, and the kind of fuel available. The requirements of a heating system are (1) it must be capable of maintaining the proper temperature for the crops to be grown, (2) it must be economical in fuel consumption and not require too close attention, (3) it must be adapted to the fuel to be used, and (4) its cost must not be out of proportion to that of the remainder of the plant and to the value of the crops to be produced.

OIL AND GAS HEATERS AND STOVES FOR SMALL GREENHOUSES.

The Department of Agriculture receives frequent inquiries as to the suitability of oil and gas heaters for small greenhouses. Such devices are adapted only to very small houses, and, owing to the

injurious effects of the products of combustion, extreme care must be taken to ventilate properly or the plants will be injured, if not killed. Such heaters should have a pipe for the removal of the products of combustion, and their use is not to be recommended except as a temporary expedient.

Coal and wood stoves are also objectionable, owing to the difficulty in obtaining an even distribution of the heat and to the dust that is always incident to their operation. It would be unwise to build a greenhouse with the intention of depending on such heaters.

FLUE HEATERS.

Flue heaters made of brick or masonry located under the benches and running the length of the house are sometimes used, and while they are superior to stoves and similar devices, only fair results can be expected from their use. Where low first cost is essential and where only crops requiring low temperatures are to be grown, their use may be advisable. They are usually constructed with the furnace at one end of the greenhouse, so that it opens into a separate room, usually the structure used as a workroom. This furnace is usually built of brick, with iron grates and iron doors which may be obtained from firms making a specialty of this type of equipment. The size of the furnace depends on the size and length of the house, but a furnace 13 inches wide, 16 inches high, and 3 feet long is large enough to heat a house 10 or 12 feet wide and 60 to 80 feet long. For the first few feet the flue is lined with fire brick with walls 9 inches thick and arched over the top; the remainder is usually ordinary building brick with 4-inch walls. In long flues the last half may be of terra cotta of suitable size, with the joints closed with fire-clay mortar. The chimney itself may be of brick or terra cotta and should be sufficiently high to give good draft. It is usually located at the opposite end of the greenhouse from the furnace, but in some cases the flue is carried around the inside of the house the entire distance, with the chimney located in the workroom or the opposite corner from the furnace. To insure draft the flue should have a slight rise from the furnace to the chimney. These heaters cause more or less dust, and in houses where they are used it is difficult to maintain the proper moisture conditions. As a means of heating greenhouses these flue heaters leave much to be desired.

STEAM AND HOT-WATER HEATING.

The gravity hot-water heating system with cast-iron boiler and large cast-iron pipe came into general use in greenhouse work as the answer to the demand for something better than the flue heater. The use of this principle in heating is not at all new, as according to historical records the Romans employed hot-water heating systems with copper boilers and copper pipe to heat hotbeds used for the production of winter luxuries. Its use in this country dates back about a half century, and improvements have been made from time to time until the modern hot-water heating system, when properly installed, is highly economical and efficient. Such a system is particularly desirable for small houses and ranges where it is impossible to give close attention to the heater, for a well-planned hot-water heating

system can be depended on to maintain a uniform temperature with a minimum of attention. In ranges containing less than 20,000 square feet of glass hot-water systems are usually looked upon as best, while for larger plants steam is believed to be more economical. In large plants where firemen are in attendance most of the time it is possible to maintain a uniform temperature with steam. Steam requires less radiation than does hot water and is usually less expensive to install. However, within the past few years the use of forced-circulation hot-water systems has brought about results comparing favorably with the most efficient steam systems. On the other hand, the development of so-called low pressure and vacuum systems has made steam heat more popular than ever. It is altogether probable that both systems will continue to have their advocates and that both will be used to a large extent. It is believed that gravity-circulation hot-water systems will prove to be the most desirable in small greenhouses.

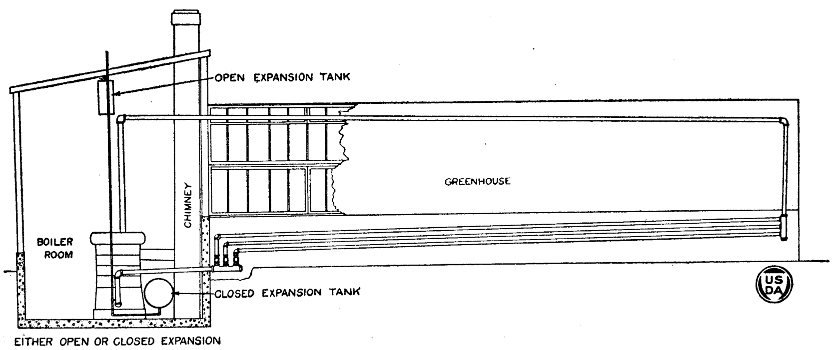

FIG. 12.—Diagram illustrating the principle of hot-water circulation.

THE GRAVITY HOT-WATER SYSTEM.

The gravity system of circulation works on the principle that hot water is lighter than cold water and the water when heated tends to rise to the highest point in the system. The principle is well illustrated by the ordinary house-range boiler, where the water is heated in the coil in the range and passes through the top pipe to the boiler, being replaced at the same time by cooler water through the bottom pipe, this process going on indefinitely. In greenhouse practice the heater is usually located lower than the heating pipes, and as the water heats in the boiler it expands and rises, forcing the cold water ahead of it, and finally makes the circuit of the system and enters the boiler through the return pipes attached near the bottom of the boiler. Figure 12 illustrates the principle upon which this system works. In practice the main or flow pipe is branched so as to provide the proper amount of radiating surface, this illustration being diagrammatic only. In the older installations it was the practice to have the highest point in the system at the end of the house farthest from the boiler, but the modern method is to have it immediately above the boiler, so that the water flows downhill for the entire distance through the house, as brought out in the diagram. The important point to bear in mind in planning a hot-water heating system is to have the pipes uniformly

graded and to avoid short turns and bends, so that the water will have an uninterrupted course through the entire system. Another important point to remember is that water expands as it warms, and as the system is filled with water it is essential to provide an expansion tank to take care of this increase in volume.

It has been found that a definite quantity of pipe surface is required to keep a greenhouse at the desired temperature. This is usually figured as square feet of pipe surface and is referred to as "feet of radiation." The most practical method for ascertaining this is by determining the number of square feet of glass in the greenhouse, and after taking into account the temperature to be maintained allow a definite amount of radiation for each 1,000 square feet of glass or its equivalent. By equivalent is meant the side walls of wood or masonry construction, 4 or 5 square feet of each side-wall surface being figured as requiring the same amount of radiation as 1 square foot of glass. Table 1 has been worked out from the experience of greenhouse builders and is as satisfactory perhaps as any that can be devised, but no table can be followed absolutely under all conditions. The geographical location, the exposure of the house to winds, the tightness of the houses themselves, and other factors must be taken into consideration in figuring radiation. The amount of radiation required must be determined by the temperature to be maintained, making proper allowances for any unusual conditions that exist. The figures given in the table are for outside temperatures of zero Fahrenheit, and where the outside temperatures are liable to go lower the radiation should be increased 1 per cent for each degree below zero; that is, for outside temperatures of 10 degrees below zero the radiation should be increased 10 per cent; 20 degrees below zero, 20 per cent, etc. In all cases it is wise to provide some surplus radiation for emergencies, so that less strain will be placed on the system during extremely cold weather.

TABLE 1.—*Temperatures to be maintained and length of pipe of different sizes needed to supply radiation for gravity-circulation hot-water systems.*

[Steam-heating systems take three-fifths of the length of pipe here stated.]

Temperatures to be maintained.	Radiation for each 1,000 feet of glass or its equivalent (square feet).	Pipe required to supply this radiation (linear feet).			Temperatures to be maintained.	Radiation for each 1,000 feet of glass or its equivalent (square feet).	Pipe required to supply this radiation (linear feet).		
		1¼-inch size.	1½-inch size.	2-inch size.			1¼-inch size.	1½-inch size.	2-inch size.
35° to 40° F......	191	438	382	305	55° to 60° F......	350	803	700	560
40° to 45° F......	225	516	449	360	60° to 65° F......	401	920	801	641
45° to 50° F......	262	602	525	420	65° to 70° F......	460	1,057	921	737
50° to 55° F......	303	696	607	486	70° to 75° F......	583	1,339	1,166	933

Table 1 is based on the use of 1¼, 1½, and 2 inch wrought-iron or steel pipe, as these are the standard sizes used for the radiating coils in greenhouse heating. In the early days of hot-water heating it was the custom to use cast-iron pipe 3½ or 4 inches in diameter. Many old houses, are to be found with cast-iron pipe of this description in

their heating coils, but in modern construction the smaller wrought-iron or steel pipe is almost universally used.

The amount of radiation necessary for houses having less than 1,000 square feet of glass exposed can readily be determined by taking fractional parts of the amount necessary for each 1,000 square feet or by taking one-tenth of the amount neccessary for each 1,000 square feet and multiplying this by the number of hundred square feet of glass exposed. In practice, it is always desirable to use one size of pipe for the mains and another size for the radiating coils.

Table 2 gives the radiating surface for each foot of pipe of different sizes and the radiation that pipes of given sizes will supply. By the use of this table the amount of radiation in the mains can be calculated and this subtracted from that to be supplied in the coils. In most cases it is a good plan to figure the radiation needed and supply it in the coils, disregarding that supplied in the mains.

TABLE 2.—*Sizes of flow pipes for various radiation requirements.*

Flow pipe.	Radiation in each foot (square feet).	Radiation supplied (square feet).		Flow pipe.	Radiation in each foot (square feet).	Radiation supplied (square feet).	
		Steam.	Hot water.			Steam.	Hot water.
1¼-inch size	0.434	90	80	4-inch size	1.175	1,200	900
1½-inch size	.494	140	130	4½-inch size	1.309	1,550	1,150
2-inch size	.622	300	250	5-inch size	1.455	1,875	1,400
2½-inch size	.753	460	350	6-inch size	1.739	2,700	2,100
3-inch size	.916	670	500	7-inch	1.966	3,700	3,000
3½-inch size	1.055	920	700				

As an example, suppose that a certain house requires 350 feet of radiation to maintain the desired temperature and that it is the purpose to use 2-inch radiating pipes. By referring to Table 2 it will be found that a 2½-inch flow pipe will supply this amount of radiation. If the house is 50 feet long and the main is to be carried the length of the house the amount of radiation in 50 feet of pipe of this size may be deducted from the amount that must be supplied by the radiating coils. According to the table 50 feet of the 2½-inch pipe contains 37.6 square feet of radiation, and this subtracted from 350, the total amount for the house, leaves 312.4 feet to be supplied by the radiating coils. Each foot of 2-inch pipe has 0.622 square foot of radiation; hence, 312.4 divided by 0.622 gives 502, the number of linear feet of 2-inch pipe that must be installed to supply the proper amount of radiation. It is, however, better practice in most cases to install the correct length of radiating pipe to heat the house, disregarding the radiation supplied by the mains.

HOT-WATER BOILERS.

Many types of hot-water boilers are available for gravity hot-water heating systems, but the cast-iron sectional boiler is largely employed in plants requiring not over 10,000 feet of radiation. Some manufacturers recommend two or more boilers for this amount of radiation. In the larger plants steel boilers are usually employed, these being either of the ordinary fire-tube type or in some cases the

Scotch Marine. In some of the later and more up-to-date plants water-tube boilers fitted with mechanical stokers are employed, these plants being as economical as those of high-grade central, power stations. The type of boiler should be adapted to the conditions rather than selected because of its being of any particular type or material. For the best results the boiler should have a greater rating than is theoretically required to maintain the desired temperature. In planning the heating system, the first step is to determine the amount of radiation needed to maintain this temperature. As a rule, a boiler having a rating in feet of 20 or 25 per cent more than the radiation required for the house will be found satisfactory. This excess will allow for differences in fuels, poor draft, and other factors. In greenhouse practice it is often impracticable to have a fireman in constant attendance, and a boiler that is somewhat larger than is absolutely needed for the work will usually give more satisfactory results than a small one that must be forced.

In small houses it is particularly desirable that the boiler be larger than is theoretically required. Many steam fitters make a practice of installing boilers having at least 200 feet greater rating than the radiation required for the house. In larger plants this margin is made much greater.

CHIMNEYS.

If satisfactory results are to be secured from the heating system the boiler must be supplied with a chimney of proper capacity. The boiler is usually fitted with a smoke-pipe opening sufficiently large to carry off the products of combustion, and if a flue be built or stack erected with the same cross section as the fitting on the boiler and of such height that it will be above near-by objects, such as trees and buildings, the results will be satisfactory. Prof. R. C. Carpenter, of Cornell University, has worked out a table giving the sizes and heights of chimneys adapted to boilers of various sizes. (See Table 3.) The figures are in inches, giving the diameter of the flue if it is round, or along one side if it is square.

TABLE 3.—*Sizes and heights of chimneys adapted to boilers of different ratings.*

Radiation rating of boiler (square feet).		Diameter of flue (in inches) for chimney of given height.					
Steam.	Hot water.	20 feet high.	30 feet high.	40 feet high.	50 feet high.	60 feet high.	80 feet high.
250	375	7.4	7.4	6.7	6.4	6.2	6.0
500	750	9.6	9.2	8.8	8.2	8.0	6.6
750	1,150	11.3	10.8	10.2	9.6	9.3	8.8
1,000	1,500	12.8	12.0	11.4	10.8	10.5	10.0
1,500	2,250	15.2	14.4	13.4	12.8	12.4	11.[illegible]
2,000	3,000	17.2	16.3	15.2	14.5	14.0	13.2
3,000	4,500	20.6	18.5	18.2	17.2	16.6	15.8
4,000	6,000	23.6	22.2	20.8	19.6	19.0	17.8
5,000	7,500	26.0	24.6	23.0	21.6	21.0	19.4
6,000	9,000	28.4	26.8	25.0	23.4	22.8	21.2
7,000	10,500	30.4	28.8	27.0	25.5	24.4	23.0
8,000	12,000	32.4	30.6	28.6	26.8	26.0	24.2
9,000	13,500	34.0	32.4	30.4	28.4	27.4	25.6
10,000	15,000	37.0	34.0	32.0	30.0	28.6	27.0

INSTALLATION OF THE GRAVITY HOT-WATER SYSTEM.

After the proper amount of radiation and the size and location of the pipes have been determined and the boiler capacity needed to supply this radiation decided on, the whole success of the heating system depends on the way it is installed. For those not thoroughly familiar with heating problems, it is better to secure the services of a trained steam fitter rather than to attempt the work with inexperienced help. It is best to locate the boiler so that its top is at a lower level than the radiating pipes in the greenhouse. While the system will work as long as the bottom fitting of the boiler is below the radiating pipes, and even when the boiler is higher than the radiation, it is best to follow the plan suggested. Boilers are tapped or fitted for pipe that is large enough to care for all the radiation the boiler will supply. Unless the boiler is much larger than is actually required, these pipes should be of full size until the first branch is reached.

In branching hot-water pipes, abrupt turns should always be avoided. The pipes should be carried in the most direct route to each junction point, using pipe bends instead of fittings wherever possible. Every short turn in a hot-water line retards the flow of the water, and the results obtained with the system are largely dependent on the care exercised in laying it out. As pointed out in an earlier paragraph, hot-water pipes must have a uniform grade or fall if good circulation is to be secured. If the pipes are uniformly graded, a fall of 4 inches in each 100 feet will give good circulation. The flow pipe leaving the top of the boiler is usually carried in a vertical direction to a point so high that there will be ample fall for the pipes to make the circuit of the houses and return with uniform grade to the bottom of the boiler. The distance between the top of the boiler and the point where the flow pipe starts in a horizontal direction varies according to conditions, but for large plants it is usually from 10 to 15 feet from the ground and in small houses just below the ridge of the house. The expansion tank as a rule is located in the boiler room and at a point somewhat higher than the highest point in the system. It is connected with the bottom of the boiler and fitted with an overflow, so that as the water expands it can rise into the expansion tank and finally overflow if necessity arises. This type is known as an open expansion tank.

Another kind, known as the closed expansion tank, is merely a steel tank holding about one-tenth the capacity of the heating system. It must be air tight and fitted with a safety valve set to operate at a pressure below that which would be dangerous to the system. It should be connected with the heating system from the bottom of the boiler, and this connection must be through the bottom of the expansion tank. This type of expansion tank can be located at any convenient point, but no valves should be placed in the line connecting it with the boiler. As the water expands it forces its way into the tank, compressing the air in the tank and putting the entire system under pressure. A typical arrangement of boiler, expansion tank, and radiating pipes is illustrated in Figure 12. In this sketch both types of expansion tank are shown, but in actual practice only one is used.

Where several greenhouses are to be heated from the same boiler the arrangement is usually such that a common header supplied by the main flow pipe from the boiler runs along the end of the houses, preferably in the potting shed or workroom, where it will be protected from the elements, and this pipe is gradually reduced in size in accordance with the amount of radiation supplied each house. A common return line is usually located underneath the floor, and this is gradually increased in size as it nears the boiler until it reaches full size at the house nearest the boiler.

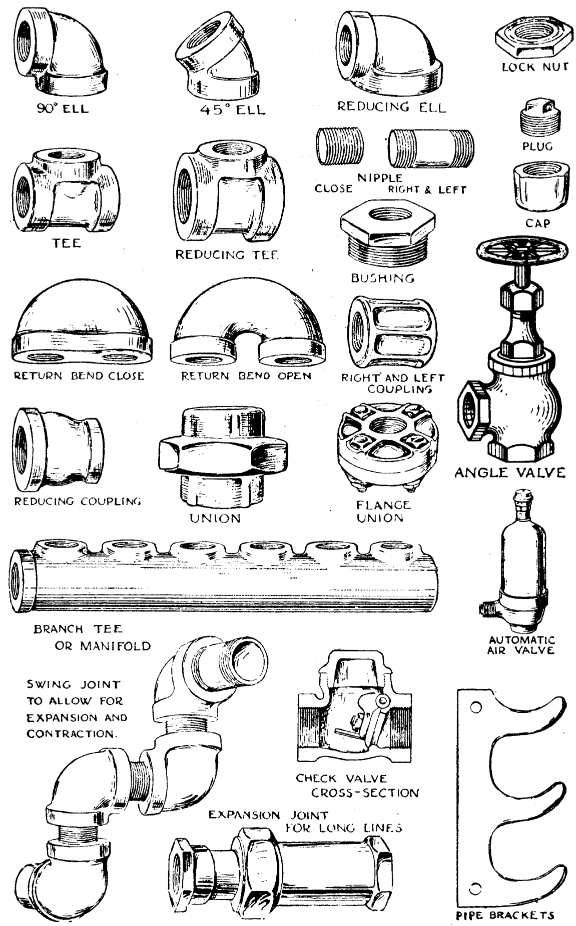

FIG. 13.—Some of the fittings used in the steam and hot-water heating systems of greenhouses.

LOCATION AND ARRANGEMENT OF THE HEATING COILS.

The location and arrangement of the piping system in the greenhouse must be planned to suit the particular house, and there are several well-defined arrangements to choose from. In general, the aim should be to secure uniform distribution of the heat and have the pipes out of the way. The usual arrangement is to have the mains or flow pipes overhead, with the radiating pipes under the benches or on the side walls or on the inside posts of wide houses. Pipes located along the side walls have a tendency to warm the cold air that enters through crevices, preventing its striking the tender plants. For small lean-to houses a good arrangement is to have the flow pipes overhead and branching into the returns at the end of the house away from the boiler, these being placed either on the side walls or under the bench. A suggested arrangement for this type of house is shown later (see Fig. 16). A system often used for small detached houses is to have the flow pipe under the ridge at such a height as to be out of the way and the return pipes placed on the side walls or under the benches. The arrangement is similar to that for the lean-to house, except that the main branches in two directions at the end

of the house away from the boiler. The plans of the 10 by 50 foot house shown further on in this bulletin (see Fig. 17) illustrate this system. In other cases the flow and return pipes are both placed overhead with the flow pipe at a higher level than the return. In wide houses, fitted with benches, the flow pipes, usually two or more in number, are carried overhead, and the radiating pipes are arranged part on the outside walls and part under the benches. There is some objection to having the flow pipes overhead, as they cast some shade and are also more or less unsightly, therefore they are sometimes placed in conduits under the walks.

Overhead flow pipes must be supported every few feet to prevent their sagging. Pieces of chain or regular pipe hangers are usually used, these being attached to the purlins or other strong parts of the greenhouse frame. It should be remembered that pipe expands about $1\frac{1}{2}$ inches in each 100 feet when heated from ordinary temperatures to the temperature of steam or boiling water, and provision must be made to care for this expansion. Swing joints, or regular telescoping expansion joints can be employed to care for this expansion, as illustrated in Figure 13. Flow pipes in conduits are usually carried on rollers, such as pieces of $1\frac{1}{2}$-inch pipe slipped over other pieces of 1-inch pipe set crosswise in the conduit and embedded in the concrete walls of the conduit. These rollers allow free expansion and contraction of the flow pipe. Provision must be made somewhere in the flow line for this expansion and contraction, as in the case of the overhead flow pipe. Radiating pipes on the side walls or the center posts are usually carried on pipe hooks, and those under the benches rest on the bench supports. It should be remembered that the weight of the water necessary to fill the system is considerable and that pipes supplied with sufficient supports to keep them from sagging when empty may not have enough support when filled. Every pipe line in the heating system should be fitted with a valve, so it can be turned on or off as the necessity may arise. Although the first cost of good valves may be considerable, their installation is advisable.

Figure 13 illustrates some of the more important parts and fittings for steam and hot-water heating systems. The use of these fittings is well understood by most steam fitters, but some of them have been designed especially for greenhouse work. Either 90-degree, 45-degree, or reducing ells are employed where it is necessary to make turns in the direction the pipe is being carried. Right-angle turns are to be avoided wherever it is possible to use pipe bends or 45-degree ells. Reducing ells are seldom used in hot-water systems but may properly be employed in the return lines of steam systems. The same is true of reducing couplings. Tees must be employed where it is desirable to take two lines from one pipe, but in hot-water systems they should be so used that the supply is not attached to the fitting on the side of the tee, as the current of water is retarded when it strikes the side of the tee. The supply from the boiler should be attached at one of the end fittings of the tee, using the other two for the branches. The right and left threaded coupling with the right and left threaded nipple and a lock washer are employed in some cases instead of an ordinary union or a flange union. Bushings have a very limited use in heating work and should be employed

only where their use is absolutely necessary. It is far better to use reducing couplings, but the best method of all is to plan the system so that reducing tees can be employed in branching the lines, thus avoiding the necessity for employing either bushings or reducing couplings. Plugs and caps are properly employed only for the purpose of temporarily closing lines where extensions are to be made. Return bends are much employed for the making up of coils of pipe for installation on walls where the pipe is only a few feet long. The open pattern is to be preferred where sufficient room is available for its use.

For greenhouse work the ordinary ground joint threaded unions are used for small-sized pipe, but for pipe above 2 inches in diameter the flange union is usually employed. Right and left couplings are employed for moderate-sized pipe, but these are seldom used for pipe larger than 2 inches. Branch tees are used where it is desirable to install several lines of radiating pipes in close proximity to each other, such as on the side walls of the house between the floor and the ventilator sash. These tees can not be used on both ends of long lines of pipe unless expansion joints are installed in each of these lines, as unequal expansion caused by some of the lines being hotter than the others will cause breakage. A method often followed to overcome this is to use one of these branch tees at one end of the radiating pipes, locating it so that the coils can be carried to a corner of the house where right and left hand ells are used to make the turn and running along the end of the house to a door where another branch tee is employed. The expansion of the pipe is cared for without placing a strain on the branch tees, but care must be taken to have the pipes far enough from the corner so they can move freely. The tee at one end of the line, usually the one near the door in the end of the house, is connected to the supply from the boiler through the tapping in the end of the tee, while the other tee is connected with the return system. Each radiating line should be fitted with a valve of the type best adapted to the conditions. The one shown in Figure 13 is known as an angle valve, but other types are available. Every set of radiating pipes, whether for steam or hot water, should be fitted with suitable means for removing air from the system. Such valves should be at the highest point in the system in which they are installed. Check valves are used in the return lines of steam systems to prevent the condensation from backing up in the system.

FORCED-CIRCULATION HOT-WATER HEATING SYSTEMS.

The forced-circulation hot-water heating system takes its name from the use of pumps to circulate the water through the mains and radiating pipes. The general arrangement of the pipes is the same as for the gravity system, except that the mains and radiating pipes may be run level if desired. Plants originally installed as gravity systems may oftentimes be greatly improved in economy and effectiveness by the installation of some suitable device for hastening the circulation. With forced circulation it is possible to maintain a given temperature with much less heating surface and usually with a lessened first cost. It should be remembered, however, that any device for hastening the circulation will necessitate the use of a

boiler much larger than that theoretically required for the amount of radiation installed. The pump used may be of any suitable type, such as the rotary or the centrifugal, and may be operated by an electric motor, a steam engine, or a gas engine, or in cases where high-pressure steam is available for their operation the direct-acting steam pump may be used. It is not ordinarily feasible to use this type in small plants, as steam is seldom available for their operation.

Improved circulation can be had, however, through the installation just above the boiler of a simple and inexpensive circulator made of ordinary pipe fittings of the size of the flow pipe in which the device is installed. Figure 14 shows in cross section the essential parts of the circulator. It can be made by any steam fitter, and the cost of its operation is small, especially when a small electric motor

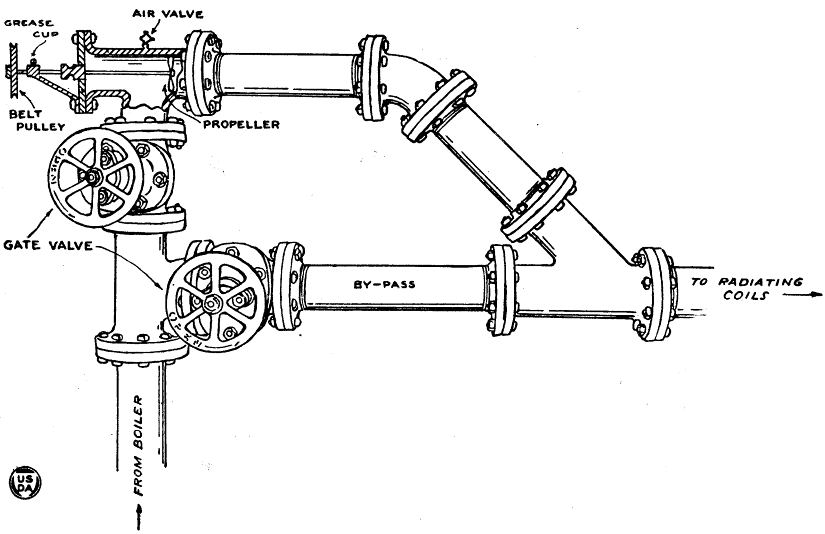

FIG. 14.—A simple hot-water circulator made of pipe and operated by power, such as an engine or a motor.

is used. As will be noted in the illustration, the stuffing box consists of the bonnet of an ordinary globe steam valve from which the valve and stem have been removed and the shaft bearing the propeller slipped through in its place. The shaft should extend out of the stuffing box far enough to give room for the bearings, collars, and the driving pulley. The bearings may be supported by a bracket attached to the riser pipe. When a motor is used to operate the circulator, it may be mounted on another bracket on the riser pipe. In assembling the circulator care should be taken to have the pulley marked so the propeller will drive the water in the correct direction. A one-fourth horsepower motor will operate the device at sufficient speed to make a distinct improvement in the circulation in the system. When high speed, with consequent increase in the rapidity of the circulation is desired, more power may be necessary. The device is fitted with a by-pass, so that it can be used or not as desired. A type of pump frequently used in forced-circulation hot-water sys-

tems is illustrated in Figure 15, this particular pump being of the rotary type.

STEAM, VAPOR, AND VACUUM HEATING SYSTEMS.

When steam is employed for heating, Table 3 can be used for figuring the radiation and the size of the boiler and chimney, but under favorable circumstances these may be reduced to three-fifths or three-fourths those required for hot water. This reduction of radiation can be obtained by the use of smaller piping throughout, but the same general principle holds as to the arrangement of the mains and radiating pipes, while the returns connecting the radiating coils in the houses to the boiler can be of small size, as they carry only condensed steam from the heating coils. More care must be exer-

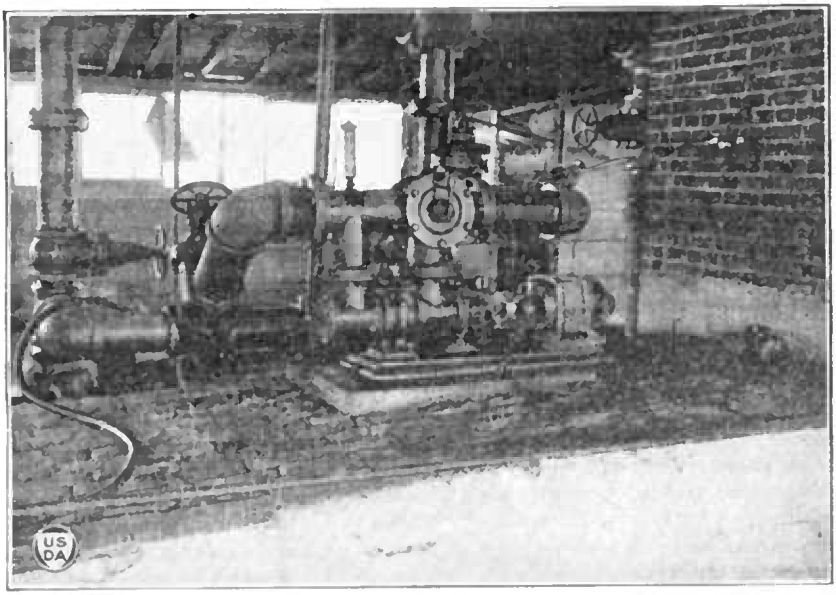

FIG. 15.—Rotary pump used in forced-circulation hot-water heating systems.

cised in the design and installation of steam systems, as the changes in temperature and the expansion is greater than is usually the case with hot water. In low-pressure systems the circulation of the steam and the return of the condensation is by gravity, but where it is necessary to use high-pressure steam to get sufficient heat, steam pumps are usually employed for returning the condensation to the boiler, as otherwise it would remain in the heating coils. Many different types of steam-heating apparatus, such as vapor and vacuum and ordinary low-pressure systems, are in use. In any of these it is necessary that the system be kept free from air. In the vacuum and the vapor systems this is usually accomplished automatically and in the case of steam systems by either automatic or hand-operated valves. In installing any form of heating system it is wise to provide plenty of air valves for freeing the system from air, as good circulation can not be secured while there are air pockets.

WATER SUPPLY.

Large quantities of water are required by greenhouse crops, and its supply should be one of the first considerations in locating and building a greenhouse. In many locations it is more economical to use a city supply, as its use makes unnecessary an extensive investment in wells, pumps, tanks, etc. Whatever the supply, its absolute reliability must be assured. When a private system is employed the water may come from any suitable source, and sufficient storage capacity should be provided to meet the needs of a day or two at least. This may be a tank on a tower, a pressure tank in the boiler room, or a reservoir on some near-by hill. The necessity for providing an absolutely reliable water system can not be overestimated.

The houses themselves should be piped so that all parts can be reached with a moderate length of hose. The supply pipes should be placed in position before the walks are laid, as it is much easier to perform the work at this time. Water pipes should not, however, be placed under concrete walks, as this necessitates breaking up the concrete when making repairs.

For many greenhouse crops overhead irrigation systems can be installed to good advantage, the use of such a system usually lessening the time spent in watering the crops. The necessary piping with inserted nozzles and other fixtures making up these systems can be installed on the pipe posts or other parts of the greenhouse structure, and the work can be done when the greenhouse is built, or if this is not practicable it can be performed at some later time.

BENCHES AND WALKS.

Greenhouse benches are expensive to install and unless of the best materials are short lived. Benches of durable construction, such as those with pipe legs and cast-iron supports and bottoms, or with iron frame and tile bottom, or of concrete, are durable but their cost is high. Wood benches are fairly satisfactory if made of cypress or other durable wood. At the present time there is a tendency to dispense with benches wherever it is possible to do so. Growers are finding that it is possible to grow many crops in ground beds, and the modern greenhouse, especially the vegetable house, is an inclosed area with only enough space occupied by walks to make it possible to handle the crops. For crops such as roses and carnations, where it is desirable that the plants be above the walks, in order that the crop may be more easily handled, this is often accomplished by either depressing the walks or by putting concrete curbs some 2 or 3 feet high along the sides of the walks and filling the beds with soil. The same results can be obtained by using boards along the walks, but such an arrangement is of a more or less temporary nature.

Greenhouse walks may be of any suitable material, such as cinders, brick, or even earth, but concrete walks are best, as these readily serve as a very satisfactory track for trucks and wheelbarrows used in handling material in the house. As little space as convenience permits should be devoted to walks, since it costs just as much to cover and heat the area occupied by walks as that in crops.

SOME GREENHOUSES SUITABLE FOR THE BEGINNER.

The greenhouse plans given on the following pages are submitted only as suggestions, for the plans can be modified to suit conditions. All the houses suggested are practical structures and well adapted to many uses, but modifications to suit the location and the particular needs of the individual can readily be made. The materials used in their construction can be varied also.

A LEAN-TO HOUSE.

The house shown in Figure 16 is a simple, inexpensive structure that can readily be built against some existing building. It is 6 feet 8 inches wide, or wide enough to make room for a walk $2\frac{1}{2}$ feet wide and a bed $3\frac{1}{2}$ or 4 feet wide. The house shown is 48 feet long, but it can be shortened or lengthened as desired. The house may be built as illustrated or the walk may be excavated to such a depth that the natural surface of the ground will be the right height to be used as a bench. This method will make the whole structure lower and will possibly lessen the cost. As figured, the house is constructed with concrete foundations and side walls, into which are embedded 2-inch iron-pipe posts fitted with special post top fittings to which is attached a wooden gutter. The construction can be modified so as to use wooden posts or to use the angle-iron eave-plate type of construction. The materials entering into the construction of such a house are simple and can be secured from firms making a specialty of such equipment.

LAYING OUT AND ERECTING THE HOUSE.

A lean-to house should have a southerly exposure, as otherwise it will be shaded for a considerable portion of the time. If built as a supplemental source of employment, when it is to receive but a portion of the operator's time, the location must be an accessible one. If the house is to be heated from some existing plant, the location must be such that this is possible. The laying out of greenhouses is similar to the laying out of other structures, and any good mechanic can readily perform the work.

The necessity for thorough workmanship can not be overemphasized. Success or failure with the house is determined largely by the way it is built. The setting of the pipe posts and the pouring of the concrete around them are matters that require painstaking care. It is best to excavate the trenches for the concrete, set the posts in position, bore holes of the proper size in the plate, slip it over the top of the posts and block it at the proper height, then attach the post top fittings and the gutter, lining it up and securing it in position before pouring the concrete in the forms previously prepared.

The placing of the ventilators, sash bars, glass, and other parts of the structure is in accordance with the suggestions made in earlier portions of this bulletin, to which the reader is referred.

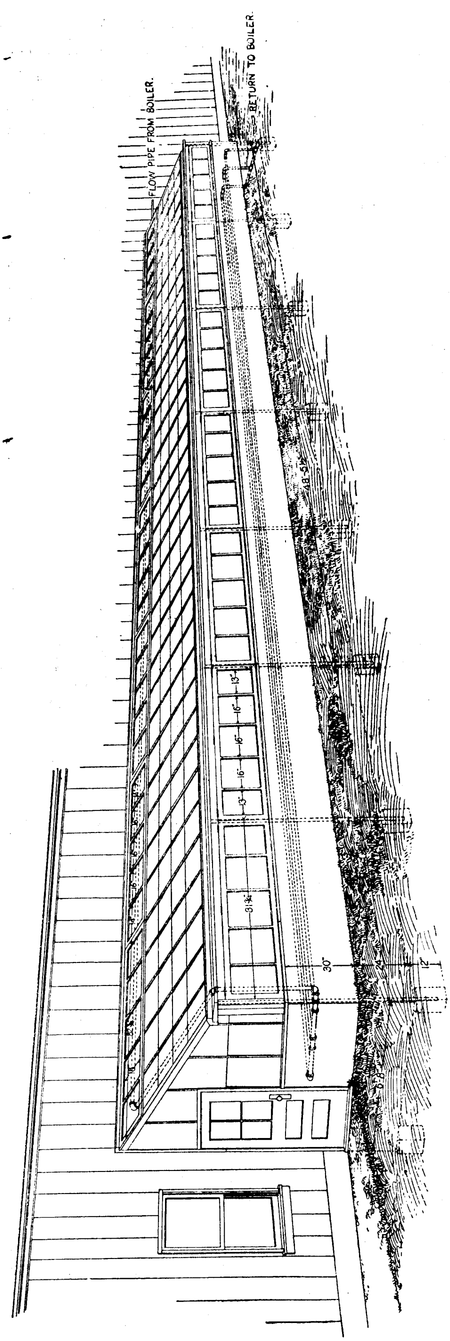

FIG. 16.—A lean-to greenhouse built against a building. This house is 6 feet 8 inches wide and may be made any reasonable length.

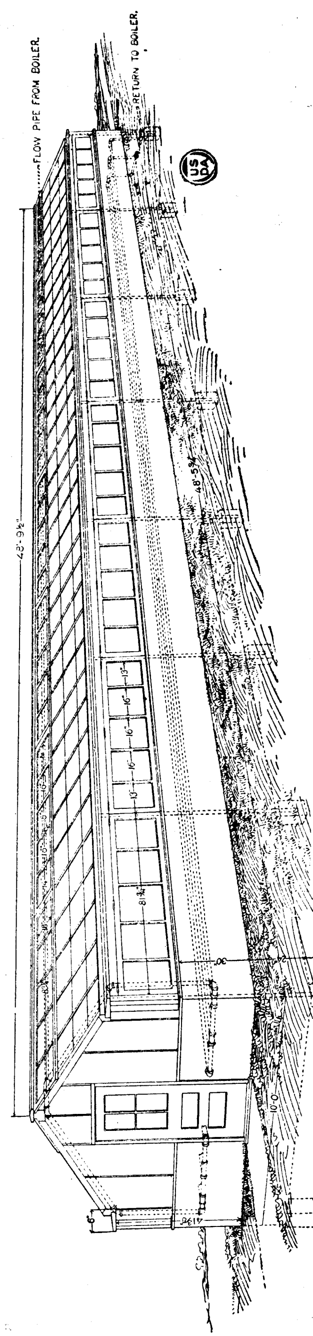

FIG. 17.—A 10-foot detached house well suited to the needs of the beginner.

THE HEATING SYSTEM.

The house may be heated in any one of a number of ways, but a gravity hot-water system is suggested as being both simple and efficient. The heat may be supplied either from a separate boiler located in a separate inclosure at the end of the greenhouse or it may be supplied from a boiler used for other purposes, such as the one serving the residence. In either case the pipe shown in Figure 16 entering the house near the ridge will be attached to the line supplying the heat. As shown in this illustration the house has about 500 square feet of wall surface taken up by the portions made up of concrete and the wall against which the house is built. The amount of radiation that should be allowed for this surface must be determined after taking into consideration the tightness of these walls and whether the building against which the house is constructed is heated or not. If heated, less radiation will be necessary, but figuring on a basis of 4 square feet of this wall surface as needing the same amount of radiation as 1 square foot of glass, this area of wall will be equivalent to 125 square feet of glass surface. The glass surface in this structure as figured in the plans is approximately 500 square feet, disregarding that contained in the ends of the structure. The radiation needed for the house, which could be determined from Table 1, is given in Table 4.

In using Table 4 always take full-length lines of pipe, even though this may give a little more radiation than theoretically is necessary. For instance, suppose it is the purpose to maintain a temperature of 35° to 40° F. and it is desired to use a 2-inch pipe, by referring to Table 4, giving the linear feet of pipe necessary to heat this house, it will be found that 183 feet will be required. Three lines of 2-inch pipe, each the length of the house, will not give sufficient radiation; hence four lines should be employed. In cases where the length of pipe required is very close to that supplied by a given number of lines it would be all right to ignore a small discrepancy. In figuring the radiation for these small houses it is usually advisable to disregard the radiation supplied by the main or flow pipe.

TABLE 4.—*Temperatures to be maintained and length of pipe of different sizes needed to supply radiation for a lean-to greenhouse.*

[Dimensions, 6¾ feet wide by 48 feet long. The radiation in the flow pipe is disregarded.]

Temperatures to be maintained.	Radiation for the 600 feet of glass or its equivalent (square feet).	Pipe required to supply this radiation (linear feet). 1¼-inch size.	1½-inch size.	2-inch size.	Temperatures to be maintained.	Radiation for the 600 feet of glass or its equivalent (square feet).	Pipe required to supply this radiation (linear feet). 1¼-inch size.	1½-inch size.	2-inch size.
35° to 40° F.	115	263	229	183	55° to 60° F.	210	482	420	336
40° to 45° F.	135	310	269	216	60° to 65° F.	241	552	481	385
45° to 50° F.	157	362	315	252	65° to 70° F.	276	634	553	442
50° to 55° F.	182	418	364	292	70° to 75° F.	350	803	700	560

The heating coils themselves may be arranged in a number of ways, but in the house shown they are placed under the bench. The main is usually placed overhead with the radiating pipes either under the bench, as shown in the illustration, or along the wall back of the bed, or partly in each location. The pipes should have ample fall and be uniformly graded so that good circulation will be secured.

A TEN-FOOT DETACHED HOUSE.

The small detached even-span house shown in Figure 17 is well adapted to the needs of persons for whom the lean-to house is not suitable and yet who want a small, simple, and inexpensive structure. This house can be constructed with low side walls about 8 inches thick, with the walk excavated below the surface, but as figured it is to be built entirely above ground. This house also can be modified to suit conditions and the needs of the owner. A good plan is to have a center walk 2 feet wide and two benches each 3 feet 4 inches wide. Whatever modifications are made in the size and shape of the structure, attention should be paid to the economical division of the space in the house. For houses fitted with benches there is no width between 10 feet and 20 feet that divides economically between walks and benches.

The house as figured has wooden gutters, but other types, such as cast iron or the angle-iron eave-plate construction, can be used. Likewise other materials than those suggested can be employed in the different parts of the structure.

There is nothing better than a gravity-circulation hot-water heating system for a house of this description. The amount of radiation for the house may readily be figured by referring to Table 1. Table 5 gives the lengths of pipe of different sizes necessary to maintain the house at various temperatures.

TABLE 5.—*Temperatures to be maintained and length of pipe of different sizes needed to supply radiation for an even-span detached greenhouse.*

[Dimensions, 10 feet wide by 48 feet long. The radiation in the flow pipe is disregarded.]

Temperatures to be maintained.	Radiation for the 840 feet of glass or equivalent (square feet).	Pipe required to supply this radiation (linear feet).			Temperatures to be maintained.	Radiation for the 840 feet of glass or equivalent (square feet).	Pipe required to supply this radiation (linear feet).		
		1¼-inch size.	1½-inch size.	2-inch size.			1¼-inch size.	1½-inch size.	2-inch size.
35° to 40° F......	160.4	368	321	256	55° to 60° F......	294.0	674	588	470
40° to 45° F......	189.0	433	377	302	60° to 65° F......	336.8	773	673	538
45° to 50° F......	220.5	506	441	353	65° to 70° F......	386.7	888	774	619
50° to 55° F......	255.0	585	510	408	70° to 75° F......	489.7	1,125	980	783

In Table 5 the number of lines of pipe of the size used that contains the number of feet of radiation nearest to that given in the table should be taken. It is always better to figure more rather than less radiation than is indicated as necessary by this table. For a house of the size specified the flow pipe should in most cases be placed under the ridge, this location making it possible to branch it in two

directions at the end away from the boiler and to connect to the radiating pipes, which may be located under the benches, as shown in Figure 17, or along the side walls, either below the benches or part in either location.

A TWENTY-FOOT DETACHED HOUSE.

Figure 18 shows a 20-foot house of semi-iron construction with two rows of inside posts. This house could be built with one row

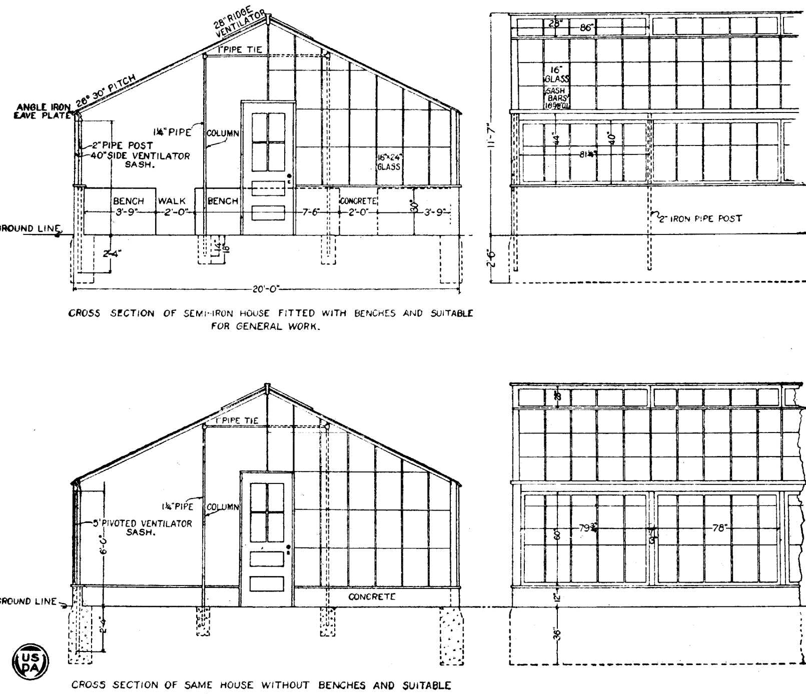

FIG. 18.—A 20-foot pipe-post, angle-iron, eave-plate house suitable for the production of either flowers or vegetables.

of pipe posts through the middle and with braces from these posts to the purlins, as brought out in Figure 8, *B*. When constructed as shown in Figure 18 with two rows of pipe posts they are always tied together by pipe ties, the whole constituting what is sometimes termed the "giant arch." This house, with side walls about 8 inches thick, has space for two side benches, each about 3 feet 9 inches wide, two walks each about 2 feet wide, and a middle bench 7 feet wide. The exact width of the benches and the walks will be determined by the thickness of the walls, and the arrangement of the house can be varied to suit the needs of the operator. The suggested proportions are believed to be as good as any, as all these benches are about as wide as a workman can reach across and the aisles as wide as necessary for ordinary greenhouse needs. When the house is to be used for vegetable growing or for the production of other crops not needing benches, the type of construction shown in the lower part of

Figure 18 may be employed. The concrete walls are low, being but 12 inches above the surface of the ground, with the remainder of the space to the eaves occupied by ventilators, or part by ventilators and part by sash-bar and glass construction.

This plan is offered only as a suggestion as to the general construction of a house of this size and description. For such a structure wooden gutters are seldom used, as the angle-iron eave-plate type of construction is greatly to be preferred. For the grower who wants a medium-sized house for general greenhouse work it is difficult to find a type of construction that is better than the semi-iron house illustrated in Figure 18. Houses of this general type with two rows of inside posts can be built as wide as 50 feet and as long as necessary.

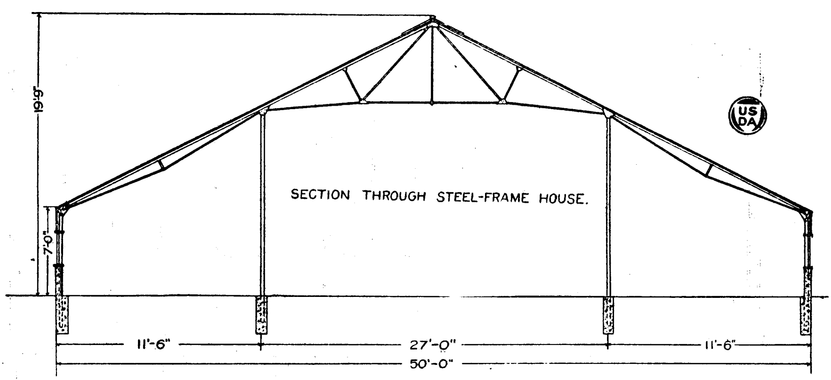

FIG. 19.—End of a steel-frame house 50 feet wide and any desired length.

The tables given in this bulletin will enable anyone to figure the amount of radiation, either steam or hot water, necessary to heat this house to any desired temperature. As an aid, however, in figuring the heating of this house the accompanying Table 6 is given.

TABLE 6.—*Temperatures to be maintained and length of pipe of different sizes needed for the greenhouse illustrated in Figure 18.*

[Dimensions, 20 feet wide by 100 feet long, containing 3,500 square feet of glass or its equivalent. The radiation in the flow pipe is disregarded.]

Temperatures to be maintained.	Pipe required to supply this radiation (linear feet).				Temperatures to be maintained.	Pipe required to supply this radiation (linear feet).			
	1½-inch size.		2-inch size.			1½-inch size.		2-inch size.	
	Steam.	Hot water.	Steam.	Hot water.		Steam.	Hot water.	Steam.	Hot water.
35° to 40° F......	802	1,337	639	1,067	55° to 60° F......	1,470	2,450	1,176	1,960
40° to 45° F......	944	1,573	756	1,260	60° to 65° F......	1,683	2,805	1,346	2,244
45° to 50° F......	1,102	1,837	882	1,470	65° to 70° F......	1,934	3,224	1,548	2,580
50° to 55° F......	1,275	2,125	1,020	1,701	70° to 75° F......	2,450	4,083	1,959	3,266

The figures given in Table 6 do not take into consideration the radiation supplied by the flow pipes. In a house of this size this is considerable, and if the house is of good construction it would be advisable to take it into consideration, reducing the radiating coils

accordingly. The arrangement of the radiating coils will be determined by the interior arrangement of the house. If the house is to be fitted with benches, as indicated in the upper part of the figure, the main or flow pipes may be placed advantageously overhead, suspended from the purlins, with the radiating coils along the side walls or under the benches, or part of them in each location. For a vege-

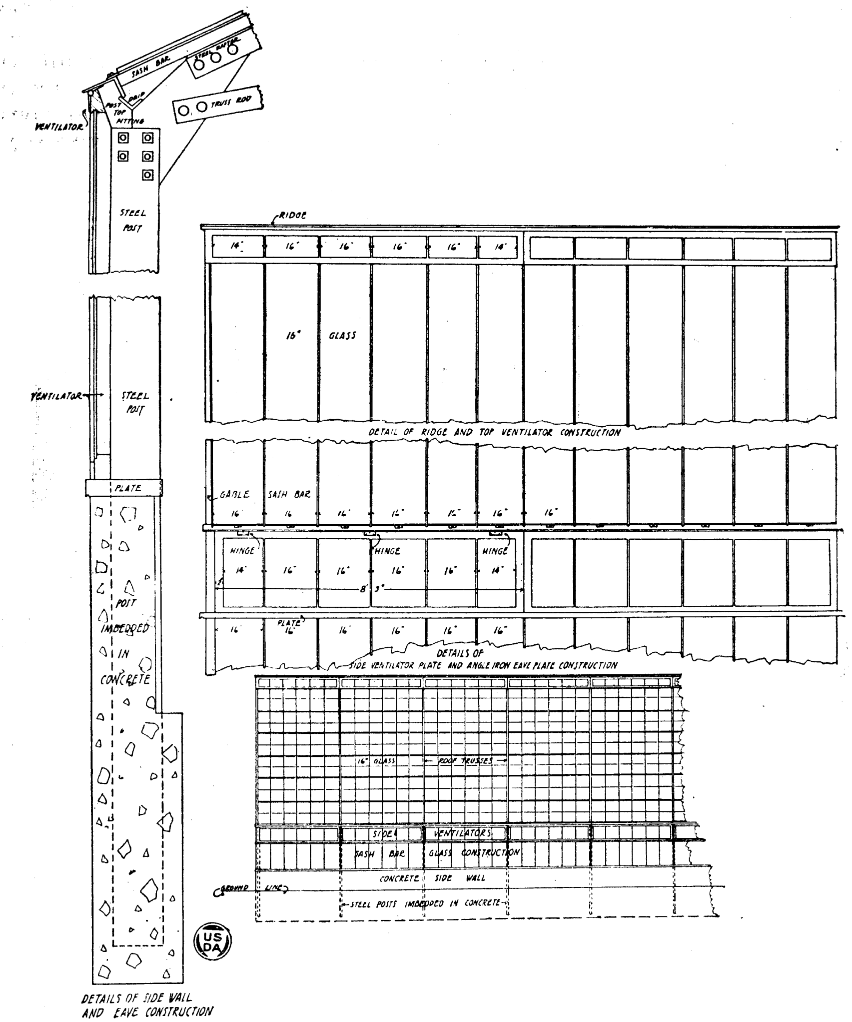

FIG. 20.—Details of construction of the steel-frame house shown in Figure 19.

table house, where, as a rule, less radiation will be installed, the logical place for the radiating pipes is on the side walls.

A FIFTY-FOOT STEEL-FRAME HOUSE.

The construction of large steel-frame houses necessitates the employment of considerable engineering skill in designing, manufacturing, and erecting the structure. Figures 19 and 20 show the

details of construction of a steel-frame house 50 feet wide, with two rows of inside posts. As figured, this house has 7-foot eaves, a 26½-degree pitch roof, and it may be as long as desired. These drawings are offered as a suggestion only, as the details of the construction can be changed to suit the conditions. As shown, the house has concrete walls 30 inches high above grade line and could be used without benches as a vegetable house or with them for the production of crops requiring such equipment. Such details as the height of the walls and the size and arrangement of the ventilators can be varied to suit conditions. The erection of houses of this type should be intrusted to men accustomed to such work, as these large structures are subject to specially severe strains from wind, snow, and ice and unless well built trouble may occur. Greenhouses of the general type shown in these figures are built as wide as 85 feet and as long as desired.

SPECIFIC INFORMATION GIVEN.

For additional information on the construction and equipment of the various types of forcing structures and for data on the forcing crops, the reader should address the Bureau of Plant Industry, United States Department of Agriculture, Washington, D. C.

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